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ABSTRACT

We have studied the inclusive production of γ, K_S^0, and Λ^0 particles in 14.75 GeV/c $\bar{p}p$ interactions. The correlations between $\pi^\pm$ and π^0, K_S^0, and Λ^0 are described and the strong correlation observed between $\pi^\pm$ and π^0 is contrasted to the apparent lack of correlation found in other hadron-hadron interactions at similar beam momenta. Invariant cross sections for γ, K_S^0, and Λ^0 production are presented as a function of x.

A recent compilation[1] of the available data on the charged-neutral correlations observed in hadron-hadron collisions with beam momenta between 12 and 1500 GeV/c has demonstrated that these correlations seem to be almost independent of the nature of the initial hadronic system. More recent π^o data from 10 GeV/c π^+p[2] and 14.3 GeV/c K^-p[3] interactions are similar to π^o data from 12 GeV/c pp collisions.[1] Furthermore, this $\pi^\pm\pi^o$ correlation has been shown[1] to be increasing monotonically from a negative correlation, dominated by energy momentum constraints, at ~ 12 GeV/c to a large positive correlation at NAL energies. This Letter reports on a study of the neutral particle production in 14.75 GeV/c $\bar{p}p$ collisions. These data represent the first results on inclusive γ production in antiproton interactions and the γ data are contrasted with data from other hadronic interactions at comparable energies.

The data presented in this Letter are obtained from an 80,000 picture exposure of the Brookhaven National Laboratory (BNL) 80-in. bubble chamber to a 14.75 GeV/c radio frequency separated antiproton beam. These preliminary results come from only a small sample of the data (12,000 pictures). Experimental details of the exposure and scanning procedure as well as results on the charged multiplicity are described elsewhere.[4]

We have measured a sample of 1107 V^o decays and γ conversions which were then fitted to the following kinematic hypotheses

$$K_s^o \to \pi^+\pi^-$$

$$\Lambda^o \to p\pi^-$$

$$\overline{\Lambda^o} \to \pi^+\overline{p}$$

$$\gamma(p) \to e^+e^-(p).$$

Events which failed the geometric and kinematics programs (TVGP and SQUAW) were remeasured twice more if necessary. In this final sample 10% of the events did not point to the primary vertex and less than 2% were deemed unmeasurable. Of the 974 fitted events, 5% were ambiguous. These were mainly K_s^o/Λ^o and $K_s^o/\overline{\Lambda^o}$ ambiguities which were finally resolved on the basis of ionization and χ^2.

In order to determine inclusive cross sections, all V^o events were weighted by a factor computed[5] from their potential decay or conversion lengths and known decay branching ratios. A minimum length requirement was also imposed on the neutral V^o particle. The resulting average weights are 23, 1.6, 1.7, and 2.2 for γ, K_s^o, Λ^o, and $\overline{\Lambda^o}$ respectively. The following inclusive cross sections have been determined from this experiment: $\sigma(\gamma)$ = 128.4±7.2 mb, $\sigma(K_s^o)$ = 1.08±0.10 mb, $\sigma(\Lambda^o)$ = 0.96±0.10 mb, and $\sigma(\overline{\Lambda^o})$ = 0.73±0.11 mb. If we assume that all the gammas come from π^o decay, we obtain $\sigma(\pi^o)$ = 64.2±3.6 mb. The $\overline{\Lambda}$ cross section is consistent with the Λ cross section as is required by the CP symmetry of the $\overline{p}p$ system. However, because of the low statistics of the $\overline{\Lambda}$ events, which tend to be fast and forward in the laboratory yielding a low detection efficiency and large potential path for secondary interactions, these events have been ignored in the ensuing discussion.

The above cross sections show that pions are by far the most abundantly produced particles from $\bar{p}p$ interactions at 14.75 GeV/c, in agreement with conclusions based on exclusive channel analyses at lower energies. Our observed ratio of $K_s^o/\pi^o \simeq 2\%$ is comparable to a value of 3% obtained in pp interactions at 19 GeV/c.[6] Using our measurement[4] of the average charge particle multiplicity, $\langle n \rangle$, and assuming that the average numbers of charged and neutral pions and kaons produced per inelastic collision are related by the following expressions:

$$\langle \pi^o \rangle = \frac{1}{2} (\langle \pi^+ \rangle + \langle \pi^- \rangle),$$

and

$$\langle K_s^o \rangle = \frac{1}{2} (\langle K^+ \rangle + \langle K^- \rangle),$$

we estimate that the average number of charged baryons (and antibaryons), $\langle n_B \rangle$, per inelastic collision in the final state is

$$\langle n_B \rangle = \langle n \rangle - 2 \langle \pi^o \rangle - 2 \langle K_s^o \rangle$$

$$= 1.05 \pm 0.08.$$

This result indicates[7] that the annihilation process accounts for ~25% of the interactions at this energy.

Figure 1 shows a compilation of the inclusive cross sections[8] for K_s^o and Λ^o production as a function of p_{lab}, the incident $\bar{p}$ laboratory momentum. Note that while $\sigma(\Lambda^{o})$ increases with p_{lab}, $\sigma(K_s^o)$ actually falls with increasing incident momentum. It is interesting to compare these cross sections with those from pp interactions. The two solid lines are interpolated from pp data which include recent NAL experiments at 102, 205, and 303 GeV/c.[9] It is observed that $\sigma(\Lambda^{o})$ exhibits a similar energy dependence in $\overline{p}p$ and pp interactions. On the other hand $\sigma(K_s^o)$ behaves very differently in these two interactions. This latter behavior may arise from the annihilation process which accounts for the large pion and kaon cross sections in $\overline{p}p$ interactions at low energies but which becomes less dominant at higher energies. If the annihilation process really accounts for the difference in energy dependence of $\sigma(K_s^o)$, the K_s^o cross section should rise for higher energy ($\gtrsim 20$ GeV/c) $\overline{p}p$ interactions. The π^o production data are consistent with the pp data in magnitude once they are normalized by the total inelastic cross section, i.e., $<\pi^o>$ in pp and $\overline{p}p$ are very similar.

The topological cross sections for π^o, K_s^o, and Λ^o production are listed in Table I together with the multiplicity dependence of $<V^o>$, the average number of V^o particles produced per inelastic $\overline{p}p$ collision. Figures 2(a), (b), and (c) display these data, and the following features may be noted. The distribution in $\sigma_n(V^o)$, plotted as a function of the associated charge multiplicity n, is broader for π^o than for K_s^o or Λ^o. The maximum value corresponds to a smaller n value with increasing V^o mass. This mass effect is also seen in the dependence of $<V^o>$ on the charge multiplicity. Whereas $<\pi^o>$ increases with multiplicity, $<K_s^o>$ is flat except for n = 0, and $<\Lambda^o>$ decreases sharply with n. The linear rise in $<\pi^o>$ with multiplicity constrasts strongly with the data from pp, π^+p, and K^-p interactions at similar energies which show a lesser dependence on n.[1-3] This is demonstrated in Fig. 2(a) which shows the 12 GeV/c pp (solid line) and 14.3 GeV/c K^-p (dotted line) data.

A recent Koba, Nielsen, and Olesen[10] scaling prediction claims that

$$\Phi(n/<n>) = \frac{<n>}{<n_{V^o}>} \frac{\sigma_n(V^o)}{\sigma_{inel}} ,$$

should be independent of the initial state energy and particles. Figure 3(a) shows that these $\bar{p}p \to K_s^o$ data are well described by the solid line which represents[11] K_s^o production in pp collisions for beam momenta greater than 50 GeV/c. A similar result has been obtained for the π^o data from this experiment.[1] However, Fig. 3(b) shows that the Λ^o data (produced mainly by target fragmentation) do not agree with the high energy pp data form and are more similar to low energy $pp \to \Lambda^o$ data.[6]

In Fig. 4(a) and (b) we show the invariant single particle distribution, $\int (2E/\pi\sqrt{s})\,(d^2\sigma/dxdp_T^2)\,dp_T^2$, and the average transverse momentum, $<p_T>$, as a function of the Feynman variable ($x = 2p_L^* s^{-\frac{1}{2}}$) for the inclusive γ and K_s^o production. We have fitted these data, integrated over all p_T^2, to an exponential form $e^{-b|x|}$. We find slope parameters for γ and K_s^o $b_\gamma = 8.13\pm0.59$ and $b_K = 2.66\pm0.43$ as compared to values of ~10 and ~5 respectively, obtained from pp interactions for a wide range of incident momentum.[12] The difference in the slope parameter, particularly in K_s^o production, can be explained by the absence of leading baryons in the annihilation process.

The data in Fig. 4(a) and (b) also show a different functional dependence in the single particle γ and K_s^o distributions. It is observed that $\langle p_T \rangle$ varies with x for γ (the well-known "seagull effect") but does not exhibit any significant dependence on x for the K_s^o production. Thus the single particle distribution cannot be separated into its x and p_T^2 dependences for γ production. The average transverse and longitudinal momenta for γ and K_s^o are $\langle p_T^\gamma \rangle = 0.16\pm0.01$, $\langle |p_L^\gamma| \rangle = 0.16\pm0.01$, $\langle p_T^K \rangle = 0.40\pm0.02$ and $\langle |p_L^K| \rangle = 0.52\pm0.04$ GeV/c. From these values, we obtain[13] $\langle p_T^2 \rangle = 0.11\pm0.01$ $(\mathrm{GeV/c})^2$ and $\langle |p_L| \rangle = 0.32\pm0.02$ GeV/c for π^o production.

Figure 4(c) shows the distribution of the reduced single particle function $1/\sigma_T \int (2E/\pi\sqrt{s})\,(d^2\sigma/dx\,dp_T^2)\,dp_T^2$ for the reactions $\bar{p}p$, $\pi^\pm p$ K^+p, and $pp \to \Lambda^o X$ at comparable energies.[14] These distributions are quite different from those for γ and K_s^o given in Fig. 4(a) and (b). The average transverse and longitudinal momenta for Λ^o production determined from the present experiment are $\langle p_T \rangle = 0.44\pm0.02$ and $\langle |p_L| \rangle = 1.15\pm0.07$ GeV/c. The Λ^o are produced by target (proton) fragmentation and if factorization is valid in a high-energy limit, the reduced single particle function should be independent of the beam particle. It is interesting to note that the function has a similar shape in all these reactions but its magnitude is higher in $\overline{p}p$ and π^-p than in π^+p, K^+p, or pp interactions. The latter is in agreement with the conjecture of Chan et al.,[15] in regard to the exoticity of Regge exchange in inclusive reactions at moderate energies.

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Table I. Cross Sections and Average Multiplicities for $\bar{p}p \rightarrow V^{o}$ + n Charged Particles.

n	σ_n mb (π^o) [a]	$<\pi^o>$	σ_n mb (K^o_s)	$<K^o_s>$	σ_n mb (Λ^o)	$<\Lambda^o>$
0	1.0±0.4	0.92±0.40	0.04±0.02	0.037±0.019	0.17±0.04	0.16±0.04
2	12.9±1.3	1.03±0.11	0.28±0.05	0.022±0.005	0.43±0.06	0.034±0.005
4	22.8±1.7	1.52±0.12	0.47±0.06	0.031±0.004	0.27±0.05	0.018±0.003
6	17.5±1.5	2.08±0.17	0.22±0.04	0.026±0.005	0.08±0.03	0.010±0.003
8	7.7±1.0	2.52±0.32	0.07±0.02	0.023±0.006	0.01±0.01	0.003±0.003
10	2.2±0.5	2.89±0.70	-	-	-	-
Total	64.2±3.6	1.57±0.09	1.08±0.10	0.026±0.003	0.96±0.10	0.023±0.003

[a]Calculated from $\sigma_n(\bar{p}p \rightarrow \pi^o X) = \sigma_n(\bar{p}p \rightarrow \gamma X)/2$.

FIGURE CAPTIONS

Fig. 1. Inclusive cross sections for K_s^o and Λ^o production. The solid curves represent data from pp collisions.

Fig. 2. σ_n and $\langle n_{V^o}\rangle$ as a function of multiplicity, for (a) π^o, (b) K_s^o, and (c) Λ^o. The solid (dotted) line in (a) is a representation of pp data at 12 GeV/c (K^-p data at 14.3 GeV/c).

Fig. 3. KNO scaling function for (a) K_s^o and (b) Λ^o data. The solid lines are obtained from fitting pp data for beam momenta greater than 50 GeV/c (see Ref. 10).

Fig. 4. Invariant cross section and average transverse momentum as a function of x for (a) γ and (b) K_s^o. (c) Invariant cross section for Λ^o production.

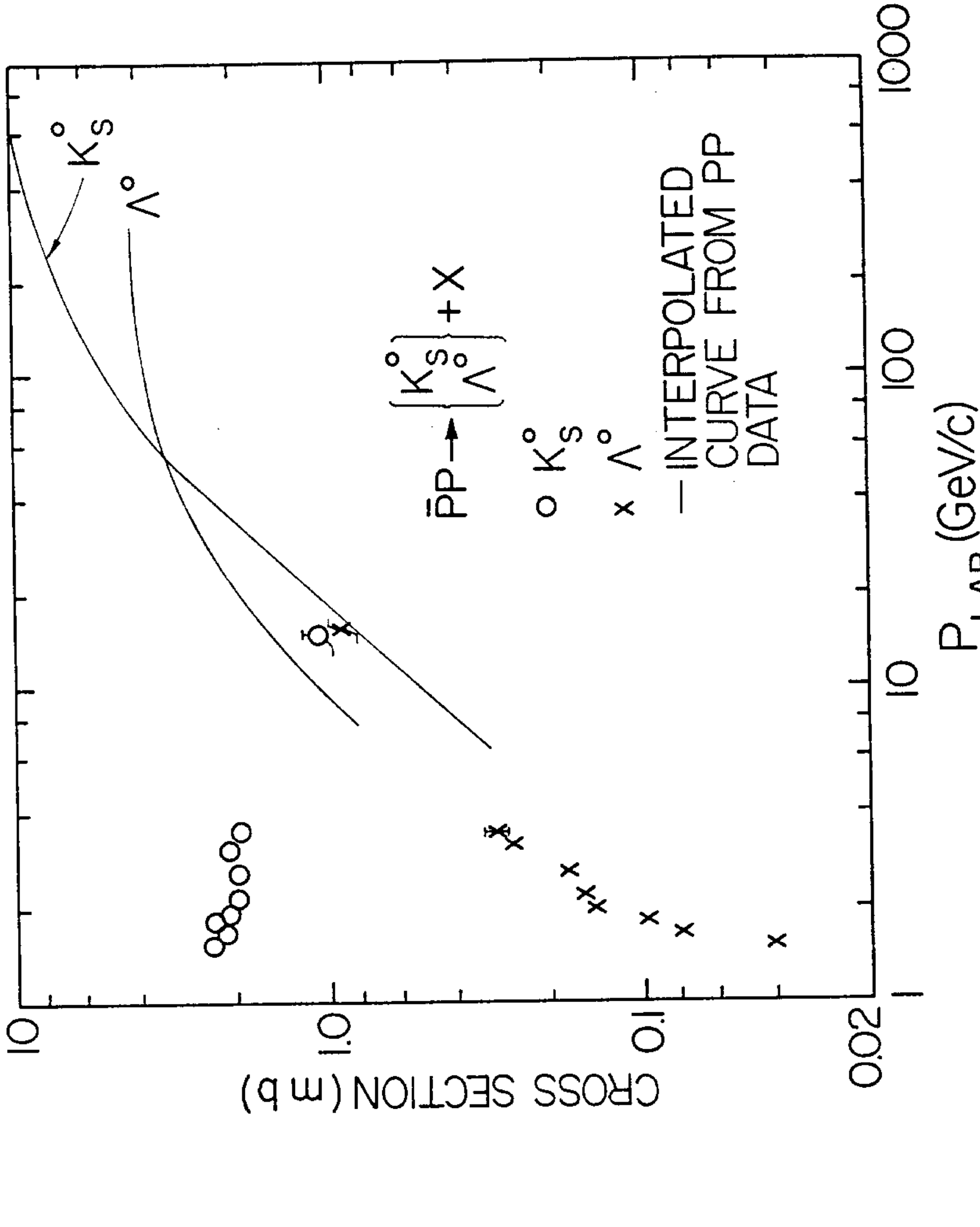
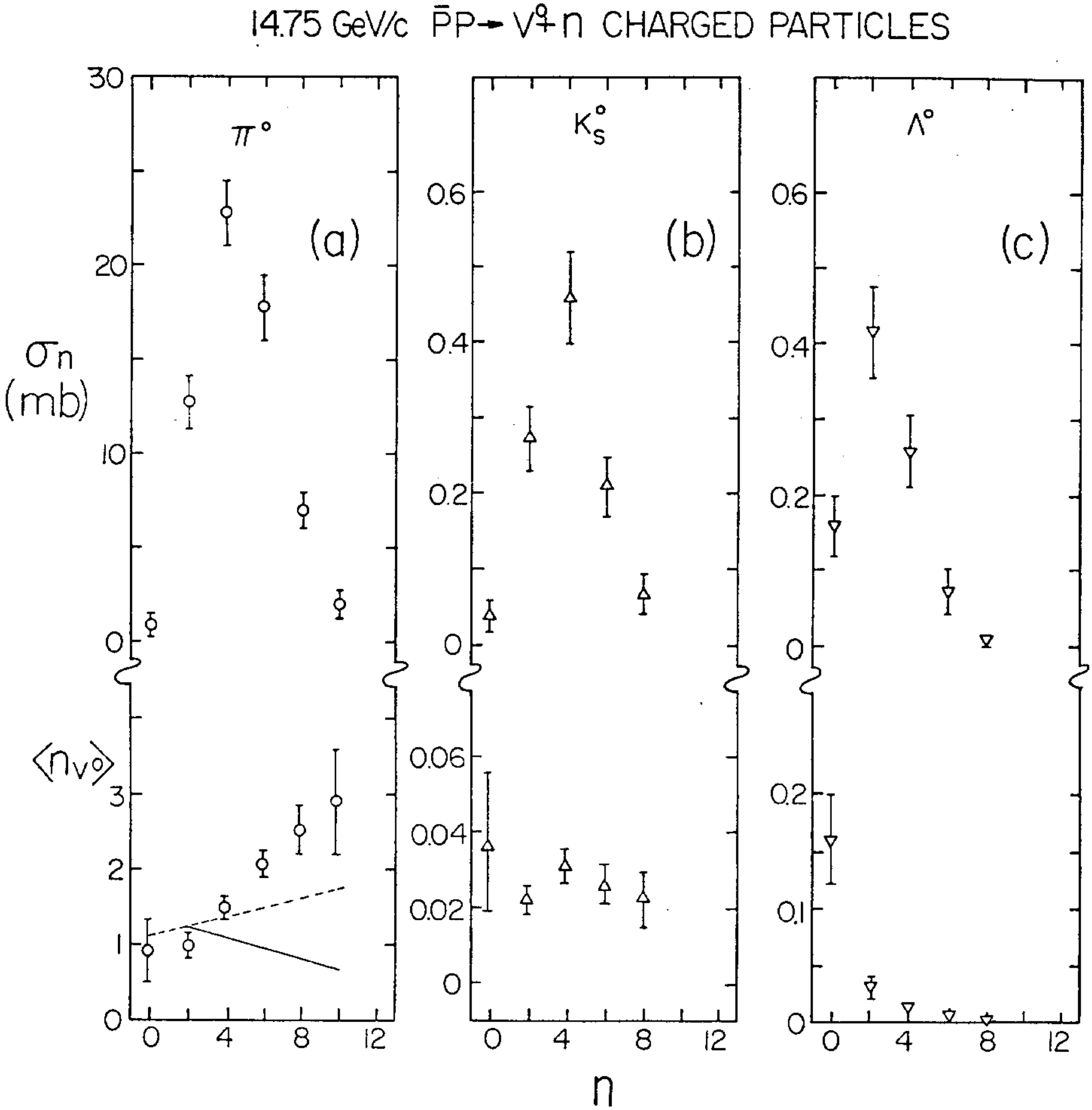
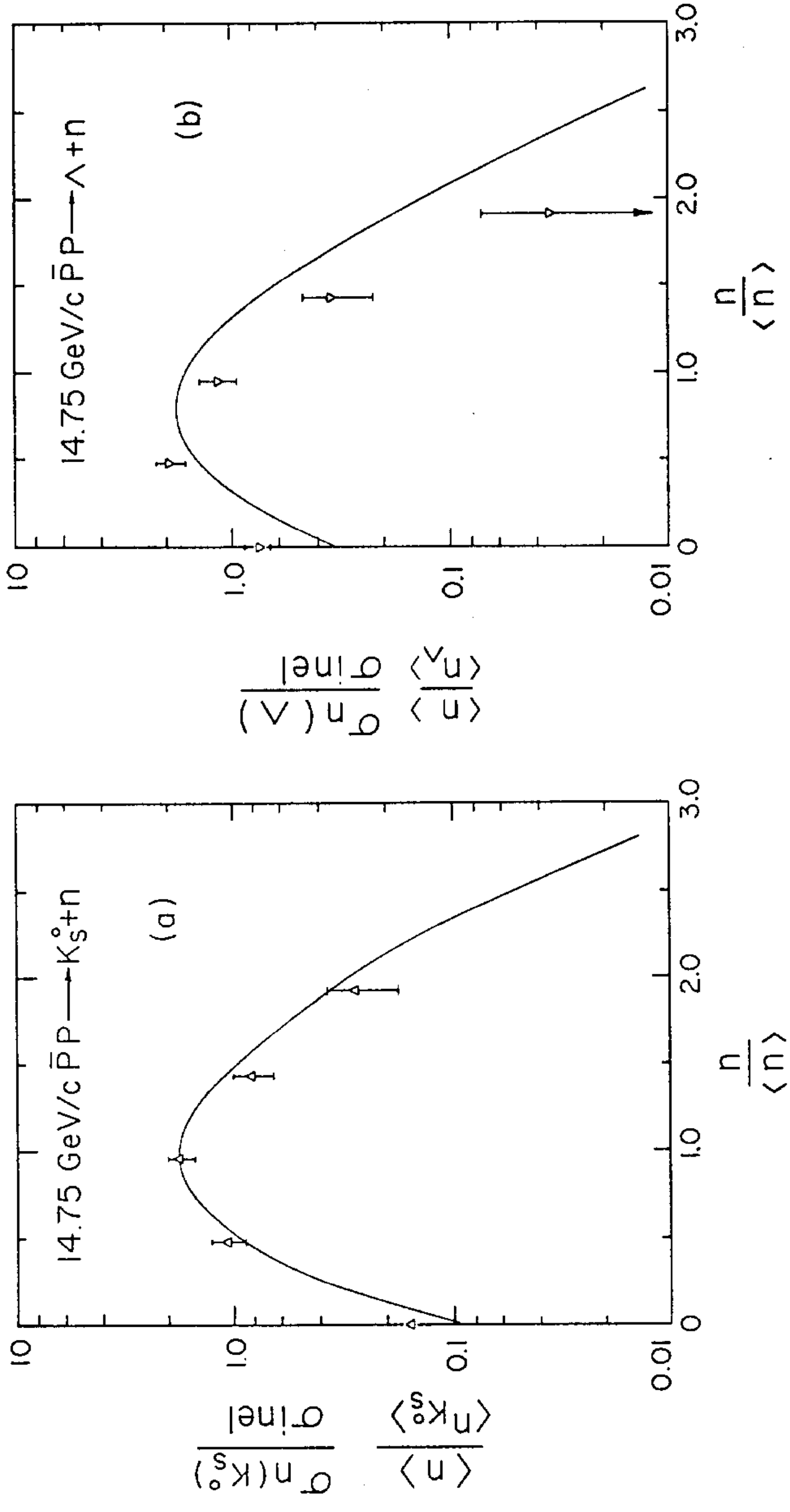

CROSS SECTION (m b)
10
1.0
0.1
0.02
1
10
100
1000
P_{LAB} (GeV/c)
K^o_S
Λ^o
$\bar{P}P \rightarrow \left\{ \begin{matrix} K^o_S \\ \Lambda^o \end{matrix} \right\} + X$
o K^o_S
x Λ^o
— INTERPOLATED CURVE FROM PP DATA

Fig. 1



14.75 GeV/c $\bar{P}P \rightarrow V^0 + n$ CHARGED PARTICLES
π^0
K_s^0
Λ^0
(a)
(b)
(c)
σ_n (mb)
$\langle n_{V^0} \rangle$
n

Fig. 2



14.75 GeV/c P̄P ⟶ Λ+n
(b)
14.75 GeV/c P̄P ⟶ K°s+n
(a)
10
1.0
0.1
0.01
0
1.0
2.0
3.0
n / ⟨n⟩
σn(Λ)/σinel ⟨n⟩/⟨nΛ⟩
σn(K°s)/σinel ⟨n⟩/⟨nK°s⟩

Fig. 3

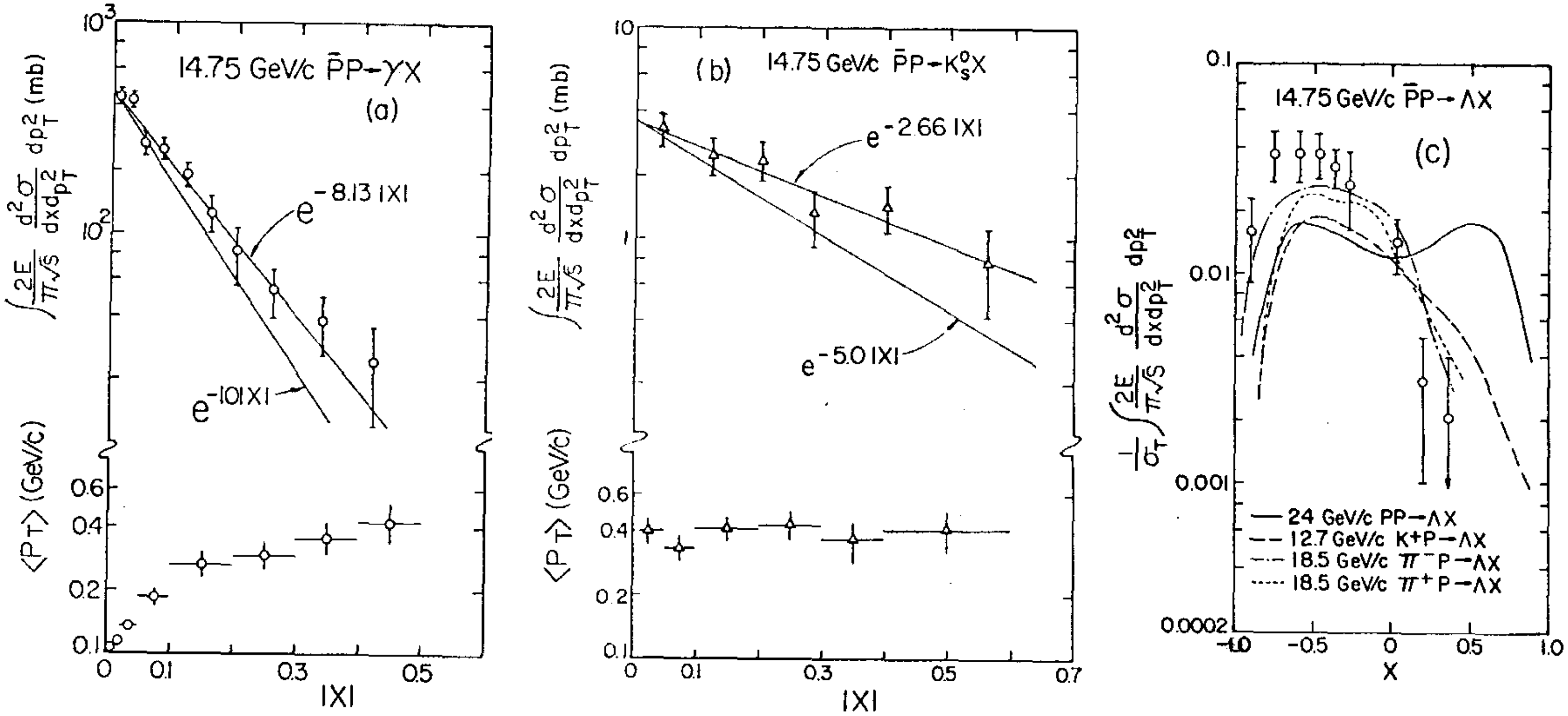

14.75 GeV/c P̄P→γX
(a)
e^{-8.13|X|}
e^{-10|X|}
⟨P_T⟩ (GeV/c)
|X|
(b)
14.75 GeV/c P̄P→K⁰_sX
e^{-2.66|X|}
e^{-5.0|X|}
⟨P_T⟩ (GeV/c)
|X|
14.75 GeV/c P̄P→ΛX
(c)
24 GeV/c PP→ΛX
12.7 GeV/c K+P→ΛX
18.5 GeV/c π⁻P→ΛX
18.5 GeV/c π⁺P→ΛX
X

Fig. 4